TMDL DEVELOPMENT FROM THE "BOTTOM UP" – PART II: USING DURATION CURVES TO CONNECT THE PIECES

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ABSTRACT

Reasonable assurance, trading, and adaptive management are key parts of the TMDL process where technical considerations intersect policy issues. Tools are needed which promote effective communication between TMDL developers and those responsible for implementing actions that will lead to measurable water quality improvements. With the large number of TMDLs that must be completed, limited resources, and the complex, inter-related nature of water programs – the "two Ps" are critical to success – *practical* approaches and *partnerships*.

Watershed analysis has been used to build a *"bottom up"* approach towards TMDL development as one way to establish a meaningful, value-added framework which links water quality concerns to proposed solutions. A *"bottom up"* approach takes advantage of networks of programs and authorities across jurisdictional lines. Information on management measures related to both source control and delivery reduction methods are incorporated into the allocation part of TMDL development. Duration curves can support a *"bottom up"* approach through enhanced targeting.

Kansas has been utilizing load duration curves for the past several years as a key part of their TMDL development process. The expanded use of flow duration curves offers an opportunity for enhanced targeting, both in TMDL development and in water quality restoration efforts. In particular, duration curves can add value to the TMDL process by identifying targeted areas, targeted programs, targeted activities, and targeted participants.

Flow duration curve analysis identifies intervals, which can be used as a general indicator of hydrologic condition (i.e. wet versus dry and to what degree). This indicator can help point problem solution discussions towards relevant watershed processes, important contributing areas, and key delivery mechanisms. These are all important considerations when identifying those controls that might be most appropriate and under what conditions. In addition, duration curves also provide a context for evaluating both monitoring data and modeling information. This offers another way to look at identifying data needs where adaptive management is being considered or utilized.

KEYWORDS

Duration curves, watershed analysis, BMP targeting, adaptive management

INTRODUCTION

A strength of the total maximum daily load (TMDL) program is its ability to support development of information-based, water quality management strategies. If done properly, a TMDL can inform, empower, and energize citizens, local communities, and States to improve water quality at the local, watershed level -- the basic information derived from a sound TMDL can liberate the creative energies of those most likely to benefit from reduced pollutant loadings to their own waters *(Tracy Mehan, November 2001)*. With this in mind, tools are needed which promote effective communication between TMDL developers and those responsible for implementing actions that will lead to measurable water quality improvements.

Reasonable assurance, trading, and adaptive management are key parts of the TMDL process where technical considerations intersect policy issues. As a result, technical achievability of pollution control practices has received an increasing amount of attention over the past several years. Two issues that often confront TMDL developers include methods to assess technical achievability and the level of precision needed to develop load reduction estimates. With the large number of TMDLs that must be completed, limited resources, and the complex, inter-related nature of water programs – the "two Ps" are critical to success – *practical* approaches and *partnerships*.

From a practitioner's perspective, there are a number of challenges associated with most technical methods. Empirical approaches rely on the existence of sufficient water quality data to adequately describe important relationships. Alternative approaches that use models require the availability of a unique expertise, information on pollutant source and delivery processes as well as watershed specific data, such as geographic information system (GIS) coverages. Furthermore, public involvement is fundamental to successful TMDL development and implementation. Key stakeholders in the watershed must be engaged in the process in order to achieve meaningful results with measurable water quality improvements. It is also a challenge to explain technical concepts and information in *"plain English"*. For instance, models must be viewed as tools, not solutions --- the use of a model does not automatically guarantee environmental improvement. Both the users and the public must understand how analytical results were derived, in order to avoid the *"paralysis through analysis"* syndrome.

"BOTTOM UP" APPROACHES

An important key to the success of the TMDL program, in terms of engaging the public, is building linkages to other programs, such as nonpoint source (NPS) management. Many successful efforts to develop TMDLs, for example, have involved the §319 program as a way to utilize local groups in data collection, analysis, and implementation. Watershed analysis has been used to build a *"bottom up"* approach towards TMDL development as another way to establish a meaningful, value-added framework which links water quality concerns to proposed solutions.

TMDL development using a *"bottom up"* approach considers the interaction between watershed processes, disturbance activities, and available methods to reduce pollutant loadings, specifically Best Management Practices (BMPs). A *"bottom up"* approach takes advantage of networks of programs and authorities across jurisdictional lines. Information on management measures related to both source control and delivery reduction methods can be incorporated into the allocation part of TMDL development.

DURATION CURVES

Duration curves can support a *"bottom up"* approach through enhanced targeting. As background, traditional approaches towards TMDL development tend to focus on targeting a single value, which typically depends on a water quality criterion and some design flow. The single number concept does not work well when dealing with impairments caused by NPS pollutant inputs *(Stiles, 2001)*. One of the more important concerns regarding nonpoint sources is variability in stream flows, which cause different loading mechanisms to dominate under different flow regimes.

Due to the wide range of variability that can occur in stream flows, hydrologists have long been interested in knowing the percentage of days in a year when given flows occur. Generally, the percentage of time during which specified flows are equaled or exceeded may be compiled in the form of a flow duration curve. This is a cumulative frequency curve of flow quantities without regard to chronology of occurrence *(Leopold, 1994)*. Duration curves may express daily, weekly, or monthly average flows. The most common form of the flow duration curve is the percentage of days in a year that the mean daily flow is equaled or exceeded

Duration curves characterize the percent occurrence of flow rates over a long period of time *(Bonta, 2002)*. Discharge rates are typically sorted from the highest value to the lowest. Using this convention, flow duration intervals are defined, which are expressed as a percentage with zero corresponding to the highest stream discharge in the record (i.e. flood conditions) and 100 to the lowest (i.e. drought conditions). Thus, a flow duration interval of eighty associated with a stream discharge of *"y"* cubic feet per second (cfs) implies that eighty percent of all observed stream discharge values are at or above *"y"* cfs.

Because NPS pollution is often driven by runoff events, TMDL development should consider factors that ensure adequate water quality across a range of flow conditions. In keeping with this idea, Kansas derived a simple TMDL development method based on duration curves, which avoids constraints associated with using a single flow number. Kansas has been utilizing duration curves for the past several years as a key part of their TMDL development process *(Stiles, 2001)*. The initial focus in Kansas was to provide a way to identify whether point or nonpoint sources are the major contributors of concern to water quality problems. Similarly, Bonta *(2002)* described the use of a derived distribution approach, which combines flow duration information with water quality data to develop concentration duration curves (CDCs) and load rate duration curves (LRDCs).

Enhanced Targeting

The expanded use of flow duration curves offers an opportunity for enhanced targeting, both in TMDL development and in water quality restoration efforts. In particular, duration curves can add value to the TMDL process by identifying targeted participants (e.g. NPDES permitees) at critical flow conditions, targeted programs (e.g. Conservation Reserve Program), targeted activities (e.g. conservation tillage or contour farming), and targeted areas (e.g. bank stabilization projects).

Flow duration intervals can be used as a general indicator of hydrologic condition (i.e. wet versus dry and to what degree). This indicator can help point problem solution discussions towards relevant watershed processes, important contributing areas, and key delivery mechanisms. These are all important considerations when identifying those controls that might be most appropriate and under what conditions.

Figure 1 represents the first of several hypothetical examples to illustrate the potential use of duration curves, both as a diagnostic indicator and as a communication tool for targeting in the TMDL process. The target curve in Figure 1 is derived using flow duration intervals that correspond to stream discharge values and numeric criteria for E. Coli. Several TMDL practitioners have described this technique *(Stiles, 2001; Sullivan, 2002; Sheely, 2002)*. The area circled on the right side of the duration curve represents hydrologic conditions where the target is exceeded, specifically low flows. In this example, wastewater treatment plants exert a significant influence at low flows. Thus, duration curves support a *"bottom up"* approach towards TMDL development and water quality restoration by identifying targeted participants, namely point sources.

***Figure 1*.** Duration Curve as General Indicator of Hydrologic Condition

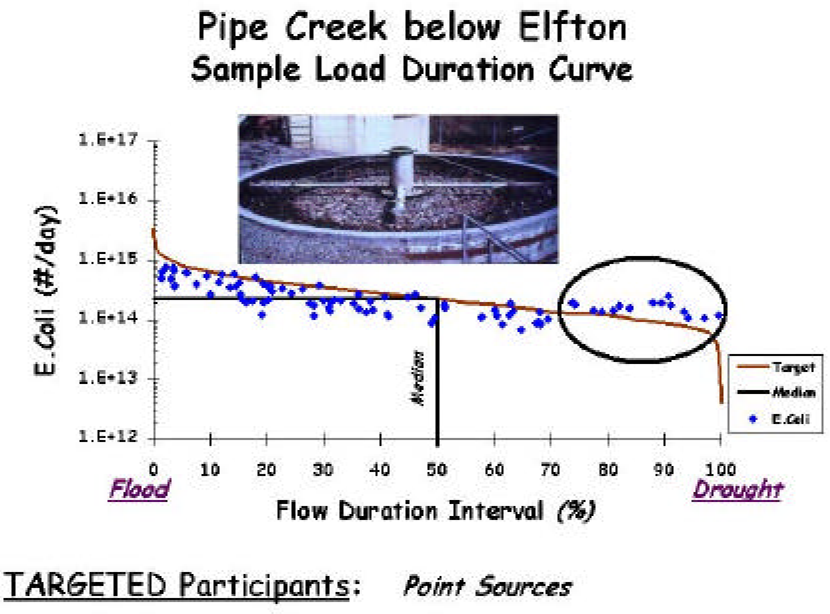
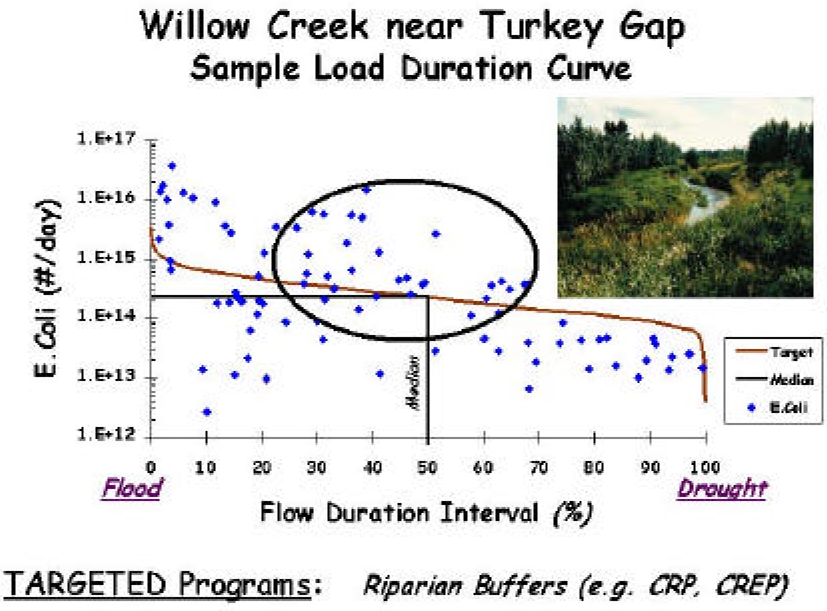


Figure 2 illustrates the added value duration curves can provide by highlighting potential contributing areas. As seen in this hypothetical example, the target is met when the hydrologic condition of the watershed is above a flow duration interval of 70 (generally dry, base flow conditions). Problems start to develop under mid-range flow conditions, as indicated by the circled area. For this particular watershed, the increases may be the result of pollutant delivery associated with rainfall and runoff from riparian areas. Again, duration curves can be used as a diagnostic tool, which supports a *"bottom up"* approach towards TMDL development and water quality restoration by identifying targeted programs, namely those focused on riparian protection.

Figure 2. Duration Curve with Contributing Area Focus



The focus on contributing areas is further illustrated with another hypothetical example, shown in Figure 3, where total suspended solids is the pollutant of concern. Here, the duration curve is expressed in terms of yield to show how derived distributions from a flow duration curve can be extended to other measures, again as a simple targeting tool. In this example, observed values only exceed the target when the hydrologic condition of the watershed is below 55 (generally higher flows). These conditions are generally associated with more saturated soils when a larger portion of the watershed drainage area is potentially contributing runoff. In this case, consideration might be given to targeted activities such as conservation tillage or contour strips.

***Figure 3*.** Duration Curve with Contributing Area Focus

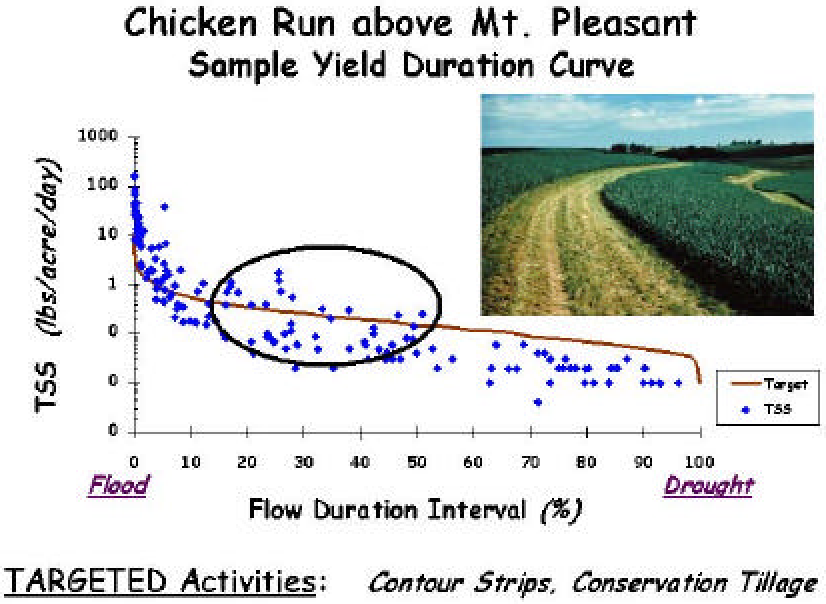
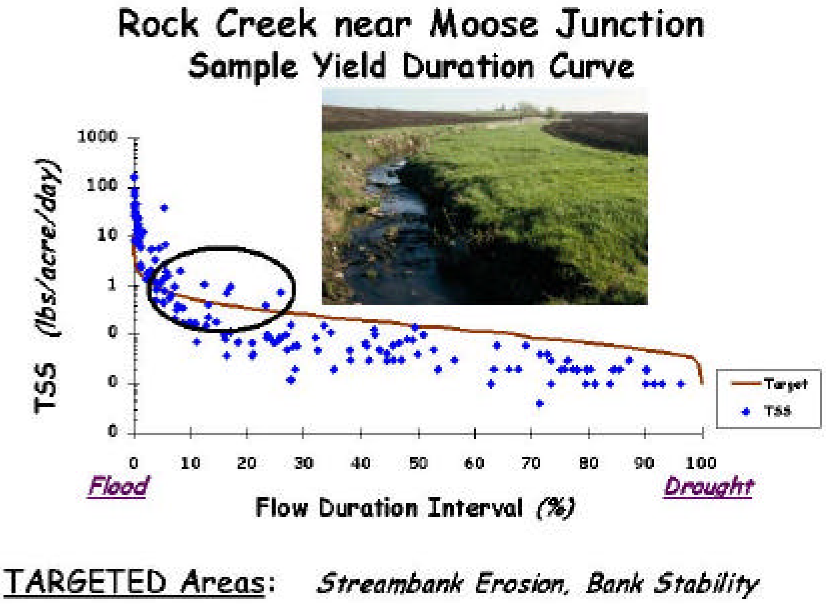


Figure 4 illustrates the last hypothetical example, which shows the potential use of duration curves as a diagnostic tool. In this situation, the target is only exceeded at intervals below 30. This hydrologic condition is associated with much higher stream discharge rates, where delivery mechanisms could include streambank erosion processes. Targeted areas to consider in a *"bottom up"* approach for this example might focus on bank stabilization efforts.

***Figure 4*.** Duration Curve with Delivery Mechanism Focus



Technical Achievability and *"Bottom Up"* Approaches

Technical achievability is a major factor generally considered when looking at reasonable assurance (another is the institutional framework to support NPS load reduction efforts, so that point source waste load allocations can fit within the TMDL). An example from the Pacific Northwest illustrates one way in which technical achievability was considered in development of a *"bottom up"* NPS-only TMDL. Specifically, the Simpson Northwest Timberlands TMDL, established by the State of Washington with technical assistance from EPA Region 10, contained allocations based on an achievability analysis.

Simpson, in accordance with the Endangered Species Act [ESA §10], developed a Habitat Conservation Plan (HCP). The Simpson HCP describes a suite of management, assessment, and monitoring actions. Simpson's conservation program emphasizes the protection of riparian forests coupled with erosion control as a primary strategy to satisfy ESA §10. Specific management prescriptions designed to reduce the input of pollutants into streams within the plan area include: riparian conservation reserves; road management; unstable slope protection; and a wetlands conservation program. Riparian management strategies in the HCP are designed to eliminate temperature increases due to human activities and to prevent delivery of excess sediment to the streams. Allocations in the TMDL are designed to achieve similar results. The allocations were derived using effective shade and sediment delivery targets based on information from the HCP.

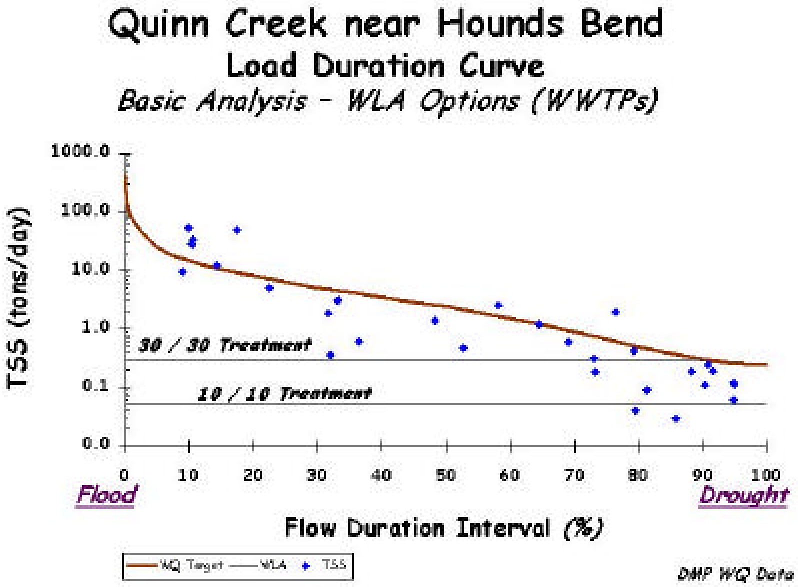
These targets were based on an analysis of expected results from implementing the HCP management prescriptions. Effective shade allocations were based on achievability estimates using channel classification information combined with characteristics of mature riparian vegetation and buffer widths associated with HCP prescriptions for each channel class. Similarly, sediment delivery allocations were based on rapid sediment budget estimates of the percent of the load that could be controlled through implementation of HCP prescriptions. Thus, TMDL development took advantage of the work underway. The measures were linked to specific source areas and to appropriate actions needed to solve identified water quality problems. This *"bottom up"* approach gives major consideration to the actions that can be implemented. Any gaps can be readily identified and filled using the concept of *"adaptive management"*.

Connecting *"Bottom Up"* Practices with *"Top Down"* Targets

When developing an analysis of technical achievability for *"blended waters"*, duration curves offer a straightforward approach. The nature of the analysis allows one to compare the relative contribution of point versus nonpoint source loads across the range of flow conditions. This can be useful when evaluating specific control options, particularly if there is variation in the effectiveness of load reduction practices based on the hydrologic condition of the watershed. In terms of pollutant trading, load duration curves can also ensure that options being considered reflect *"apples for apples"* rather than *"apples for oranges"*.

Figure 5 uses a simple example to illustrate the use of load duration curves in an achievability analysis. This example starts with an evaluation of point source contributions in the watershed. These are relatively continuous discharges that do not exhibit the wide range of flow variation observed with NPS inputs. Figure 5 shows how possible allocations might look using two different treatment options.

Figure 5. Waste Load Allocation Options Using a Duration Curve Approach



Depending on watershed characteristics, a logical next step that extends the achievability analysis to nonpoint sources could focus on those contributing areas most likely to deliver runoff generated during low flow conditions, such as riparian areas. The analysis might consider, for example, a range of buffer widths that could be applied to different channel types in the watershed. Figure 6 illustrates one possible way, using duration curves, to frame an evaluation of load allocation options regarding estimated pollutant reductions from riparian areas.

Similarly, extending the analysis to consider other potential NPS inputs could focus on expected load reduction estimates that might be achieved using BMPs appropriate to the source area / delivery mechanism of concern. One example might be estimating expected load reductions to be achieved using grassed waterways or conservation tillage. The resulting TMDL would be the aggregate analysis of practices considered for implementation in the watershed plan. Figure 7 illustrates the concept using duration curves to aggregate load reduction estimates for point sources and riparian areas. This approach highlights critical conditions to consider in the development of TMDL allocation strategies. This approach can also help distinguish legitimate trading options from those that target different conditions.

***Figure 6*.** Load Allocation Options Using a Duration Curve Approach

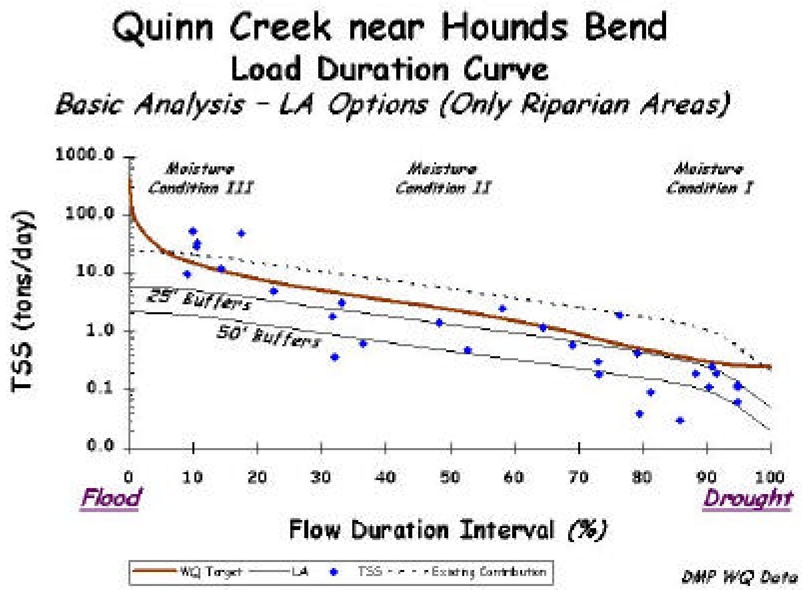
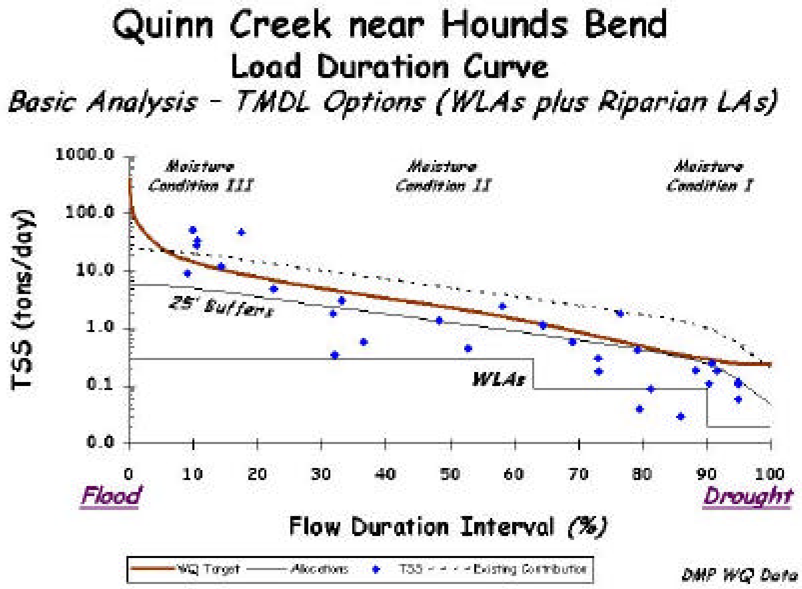


***Figure 7*.** Using Duration Curves to Evaluate Allocation Strategies



ADAPTIVE MANAGEMENT

Duration curves also provide a context for evaluating both monitoring data and modeling information. This offers another way to look at identifying data needs where adaptive management is being considered or utilized. Specifically, adaptive management plays a key role in the implementation process for achieving load reductions. Using a value-added *"bottom up"* approach, TMDL development occurs using the best available data. Progress towards achieving load allocations are periodically assessed through phased implementation using measurable milestones.

Adaptive management must be built into the process from the beginning. If a TMDL process or design does not have a component that can incorporate mid-course corrections, uncertainty and the differing views people have on it will hamper success *(Poole, 2001)*. Developing a policy that incorporates adaptive management can help resolve the problem. Under adaptive management, a watershed plan should not be held up due to a lack of data and information for the *"perfect solution"*. The process should use an iterative approach that continues while better data are collected, results analyzed, and the watershed plan enhanced, as appropriate. Thus, implementation can focus on a cumulative reduction in loadings under a plan that is flexible enough to allow for refinement, which better reflects the current state of knowledge about the system and is able to incorporate new, innovative techniques.

SUMMARY

A *"bottom up"* approach towards TMDL development is one way to establish a meaningful, value-added framework which links water quality concerns to proposed solutions. TMDL development using a *"bottom up"* approach considers the interaction between watershed processes, disturbance activities, and available methods to reduce pollutant loadings, specifically BMPs. A *"bottom up"* approach also takes advantage of networks of programs and authorities across jurisdictional lines. Information on management measures related to both source control and delivery reduction methods can be incorporated into the allocation part of TMDL development.

Duration curves can support a *"bottom up"* approach through enhanced targeting. Traditional approaches towards TMDL development tend to focus on targeting a single value, typically dependent on a criterion and some design flow. Single number concepts do not work well when dealing with impairments caused by NPS pollutants. Because NPS pollution is often driven by runoff events, TMDL development should consider factors that ensure adequate water quality across a range of flow conditions.

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